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HIGH PRESSURE WATER JET CUTTING AND STRIPPING

David T. Hoppe
Majid K. Babai
Process Engineering Division
Materials & Process Laboratory
Marshall Space Flight Center, Alabama 35812

ABSTRACT

High pressure water cutting techniques have a wide range of applications to the American space effort. Hydroblasting techniques are commonly used during the refurbishment of the reusable solid rocket motors. The process can be controlled to strip a thermal protective ablator without incurring any damage to the painted surface underneath by using a variation of possible parameters. Hydroblasting is a technique which is easily automated. Automation removes personnel from the hostile environment of the high pressure water. Computer controlled robots can perform the same task in a fraction of the time that would be required by manual operation.

INTRODUCTION

Pressurized water cleaning is not a new technology, but it is a process which can always discover new applications. Low pressure water cleaning is an every day occurrence. We wash down driveways with a garden hose, run our cars through magic wand car washes, and rinse plates under the kitchen faucet. Water dissipates a large quantity of energy as it flows which is just waiting to be harnessed. This is seen dramatically in the production of electricity at a hydro electric dam and more subtlety from erosion in our streams and oceans. Pressurized water cleaning utilizes both the force from the impact of water droplets and the frictional erosion force as water flows over the material to cut through and drag particulate matter away. High pressure water cleaning, referred to as hydroblasting, amplifies this power in water to the nth degree. What takes nature years to accomplish, can be performed in minutes at high pressure. A pressure of 10,000 - 15,000 psi is typically used to clean up a solid rocket motor after its retrieval from the ocean. Pressure of 50,000 - 60,000 psi can cleanly cut through the toughest materials.

BACKGROUND

The solid rocket motors are retrieved and refurbished after each shuttle flight. With a goal of at least five to six shuttle flights per year and two solid rocket booster motors (SRBs) per shuttle, refurbishment of the SRBs are an important part of keeping NASA's fleet in operation. Hydroblasting is an important and effective step in the refurbishment process. Each SRB is covered with a protective coating of material to protect the base metal from the heat and intense frictional force experienced by the SRBs as they propel the shuttle at incredible speeds, as well as the corrosive ocean environment. These materials referred to as the Thermal Protection System (TPS) must be stripped from the SRB as it is disassembled. Obviously, since TPS is designed to resist these intense frictional forces, it is not easily removed. Once the TPS is removed, the painted surface is inspected. If the top coat has been damaged it too is stripped off. The base coat can also then be stripped if necessary. The variation of several parameters control the stripping effectiveness of the water spray. The angle of incidence of the water to the SRB, water pressure, flow rate, type of nozzle, distance between nozzle and SRB, water jet traversing speed, and direction of water jet traverse all have an effect on the process and must be optimized to produce the desired stripping results.

These parameters cannot be effectively controlled by manual operation which results in excessive processing time due to the reduced efficiency. Manual operation of a hydroblast system is also a dangerous and difficult operation. The effect of the strain of manual operation, can be compared to the mess generated while washing a car combined with the noise and fatigue from operating a jack hammer. Controlling a water stream at a pressure that can slice through the TPS places the operator in constant peril of being cut himself by the water spray. An operator must wear full body protection and a face shield equipped with an air hose. The operator must resist a 75 pound backthrust which is produced from a water spray pressure of 10,000 psi. To remove the operator from the direct contact with the water spray, the hydroblast process has been automated with the aid of a computerized robot. Operators can then set behind the console of a computer in an airconditioned and sound proofed control room. The hydroblast system setup for the removal of TPS from the SRB aft skirt is shown in Figure 1.

AUTOMATED SYSTEM OPERATION

The hydroblast refurbishment facility installed in hanger AF at Kennedy Space Center was developed in the Productivity Enhancement Facility at the Marshall Space Flight Center (MSFC). The hydroblast system designed at MSFC utilizes a frequency control Hammelmann pump system. A water diversion system switches the water flow between different nozzles without physically removing and installing the nozzles. The nozzles to be used are attached to the end of a six axis of freedom, hydraulic operated robot which is set on a lift table. The robot arm can resist 225 pounds of reaction force and maintain an accuracy of 50 mils. This allows full access to an entire section of a component of the SRB directly in front of the robot. The component sets on a turntable which rotates the component in front of the robot allowing full coverage of the component by the robot. The turntable has an angular positioning accuracy of one quarter of a degree. A DEC PDP 11/23 computer controls and synchronizes the robot program, pump pressure and water flow rate, and the turntable location and speed. The hydroblast system components are shown in Figure 2.

Parameter optimization must be performed for each material the hydroblast is used to remove. TPS materials which have effectively been removed by the hydroblast include specially formulated Marshall Sprayable Ablatives (MSA), K5NA, Marshall Trowellable Ablator (MTA), PRC - 1422, and Cork. Gloss white Bostick Epoxy paint #443-3-1, different types of adhesives, and even three inch thick insulation. Although each material has its own characteristics, some general principles can be applied to any material however. Stripping material from the top down reduces the interference with the water stream by the material as it is removed. It is best to have the angle of incidence directed toward the material to be removed. After the water jet cuts through the material, it penetrates between the metal surface and the material to be removed which aids the stripping of the next pass. A glancing angle of incidence was found to be best for stripping TPS without damaging the topcoat of paint. A near perpendicular angle of incidence was more effective at removing the white Bostick top coat.

At a 30 degree angle of incidence, a twenty four inch water jet length between the nozzle and the SRB component was found to be optimal for removal of TPS. This physically placed the nozzle within twelve inches of the SRB. At a twenty-four inch water jet length, the water spray pattern impacts the component before it can dissipate. A water jet length less than twenty-four inches results in a more concentrated impact pattern and although this would yield a stronger stripping force, the smaller removal area results in less efficient stripping. A water jet length of eighteen inches proved effective for the removal of the top coat of paint. Conventional nozzles proved to be inadequate for the high pressures associated with the hydroblast system. These nozzles showed low stripping performance and high erosion degradation due to inefficient flow characteristics. The available nozzles were rated at 10,000 psi or lower. High Pressure Full Tapered Stripping (FTS) nozzles were designed with a long convergence before the exit orifice in order to raise the performance to an acceptable level. These nozzles were also manufactured from a tougher steel. The operation of the automated hydroblast robot has resulted in an estimated savings of $52,000 per launch.

PROCESS ENHANCEMENT AT MSFC

An additional process enhancement investigated was the use of a rotating nozzle. A twin jet nozzle fixed on a rotating hub is turned by the back pressure of the water jet. Moving the position of magnets within the housing changes the amount of resisting force to provide speed control over the nozzle rotation. At 15,000 psi, a rotational speed of 1500 rpm is possible. This rotating nozzle removes a much wider strip across the material at each pass. Test results show this to be effective at removing TPS type material but not paint.

Dry grit blasting is a common stripping process and is generally required to remove paints, especially primer coats. Dry blasting methods used to remove paint and primers greatly increase the time and cost for processing. Combining grit blasting with hydroblasting will greatly reduce the refurbishment time and movement and handling of hardware required. A mixing chamber is added to the nozzle assembly. A gravity feed hopper is connected to the nozzle mixing chamber where the vacuum created by the water flow through the nozzle pulls in the grit material. Crushed walnut shells have proven to be an excellent grit material for the removal of primer paint. The crushed walnut shells are soft enough to prevent impact damage to most base materials.

Caution and testing must be performed before any production usage of the hydroblast can be performed. The high pressure water spray is a potent force. At 15,000 psi, a water spray that is allowed to dwell at the same point on an aluminum plate will cut into the plate and if left long enough would eventually cut all the way through. It is a good habit to start the robot or turntable motion before the pressure is increased or to increase the pressure while the spray is being dissipated into the air surrounding the part to be hydroblasted in order to preclude this possibility. Several feet is all that is required to spread the water blast spray out into turbulence and quickly dissipate its energy.

The extremely high pressurized water spray is used for cutting many materials. The walnut shell grit injection is used with pressures up to 60,000 psi to accomplish an extremely effective cutting process. The high pressure produces a flow rate at three times the speed of sound. Special sapphire nozzles must be used because of the high erosion characteristics of this flow. Even though it cuts fairly cleanly, final milling of the part would still be desireable. The ultra high pressure water cutting referred to as the water knife can reach and effectively cut through parts where conventional cutting techniques cannot reach. The water knife has been coupled to a tracer mill to quickly cut out patterns in hard materials such as inconel in a fraction of the time usually required to rough cut these materials. It is effective on composite materials slicing through the fibers without causing fraying.

MOBILE ROBOT

This automated robot is great for regular and repeatable operations, but some of the SRB refurbishment requirements are not so easily isolated or have easy access. Even after several years of use there have been areas on the SRBs that required manual attention, until now. Marshall Space Flight Center (MSFC) has recently developed a mobile robot to eliminate these last manual hydroblast requirements. The Mobile Robotic Hydrolasing System (MRHS) utilizes a six degree of freedom articulated robot mounted on a transportable platform. The vehicle can be raised up to 34 inches off the ground by four hydraulic cylinders for extra reach towards the tallest points on the SRB. Air conditioning and soundproofing were added to the cab's new watertight plexiglass cabin, creating an enclosure that will protect the operators and robot's controller from heat, humidity and debris. The robot is electric but has similar capabilities to the hydraulic robot. The MRHS includes similar diversion valve switching between nozzles. Also included were an inclinometer for deck leveling and a displacement transducer to input the deck height to the robot's controller for verification and added safety.

This unit, which is first of it's kind, can be maneuvered around the boosters. The robot's end effector holding the nozzles can withstand the delivery of 25 gallons of water per minute under 15,000 psi pressure. The nozzle assembly moves through a smooth preprogrammed robotic path removing TPS from the boosters. This is twice the flow rate of water which can be handled manually, with a consistent repeatability of 0.02 inch accuracy. It improves quality of the TPS stripping and increases personnel and hardware safety while reducing refurbishment time. It has been conservatively estimated that the system can save 20 hours of serial time per flight set. This equates to a 40 percent reduction in TPS removal time prior to SRB disassembly at an estimated savings of $67,200 per launch. As to its untapped potentials, what the Mobile Robot offers is a prototype for a traveling, ergonomic control center with attached robot that could expel mediums other than water. Already under evaluation at MSFC and USBI is its feasibility for sealant application, paint spraying, and wet ablator insulation. This system has applications yet to be imagined for other NASA programs, for the military and commercial aerospace. The conceptual design for the mobile robot is shown if Figure 3.

CONCLUSION

Hydroblast stripping procedures have proven to be an important part of the refurbishment of solid rocket motors. The fully integrated computer controlled hydroblast system provides a safe and efficient facility for the refurbishment cycle. The development of the Automated Water Blast Research Cell at the Productivity Enhancement Facility has resulted in the savings of millions of dollars and hours of precious processing time at Kennedy Space Center. The newly developed mobile robot has further increased the savings in cost and time. The technology developed for the mobile robot can be used for new applications of the mobile robot concept. New usage for the hydroblast system are always being discovered for hard to remove materials. The hydroblast system has proven to be one of the most reliable and adroit systems at both the Marshall Space Flight Center and the Kennedy Space Flight Center.

ACKNOWLEDGEMENTS

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Robert Rice, Steve Cosby, and Fletcher Burgess and associates of USBI have been instrumental in the installation, operation and optimization of the hydroblast process.

REFERENCES

Robert M. Rice, "Process Report on the Automated Hydro Removal of TPS" prepared for NASA, Contract NAS8-36300, January 1986.

AUTOMATED TPS REMOVAL FROM SRB AFT SKIRT

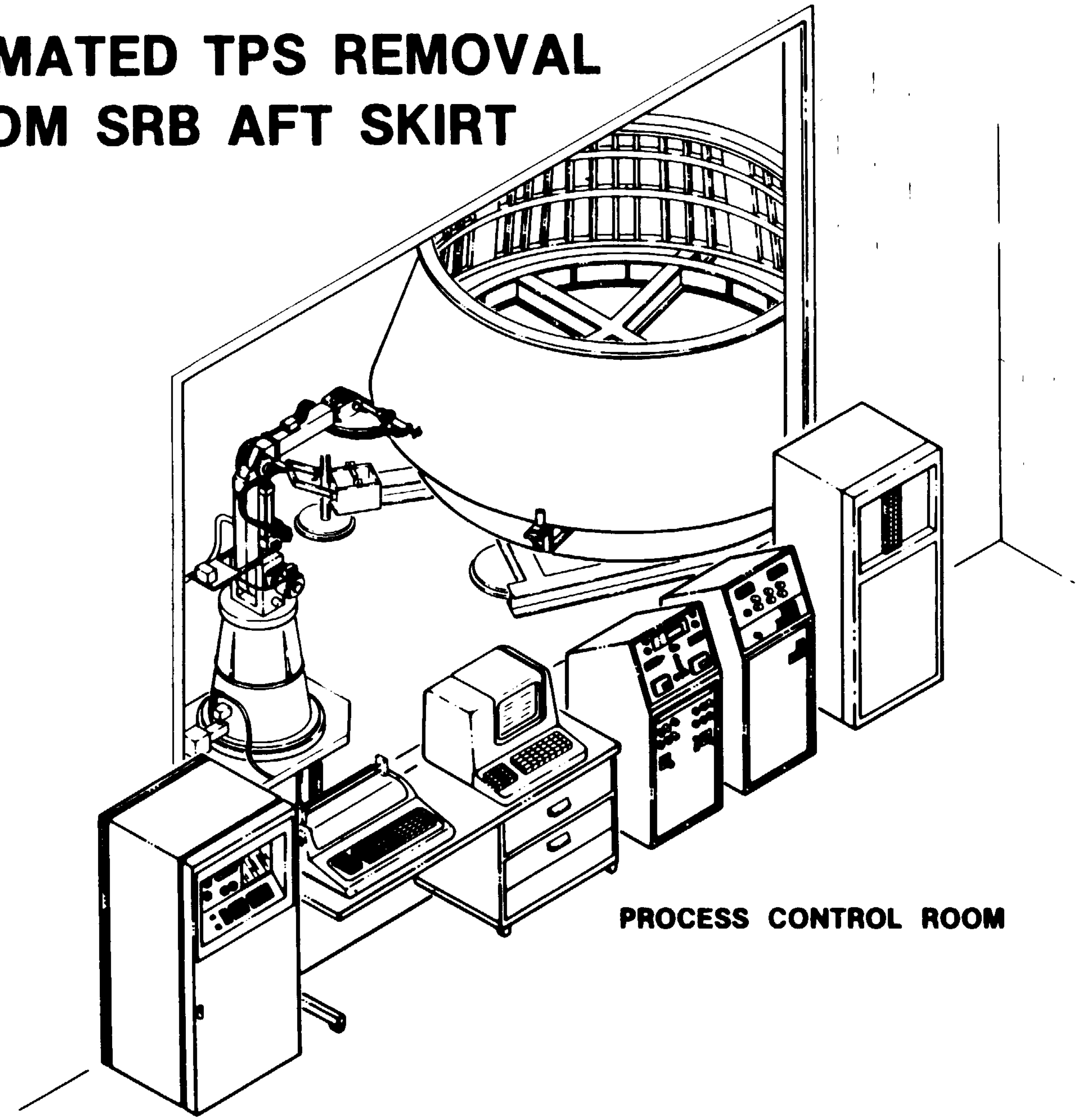

FIGURE 1

SRB AUTOMATED TPS REMOVAL SYSTEM

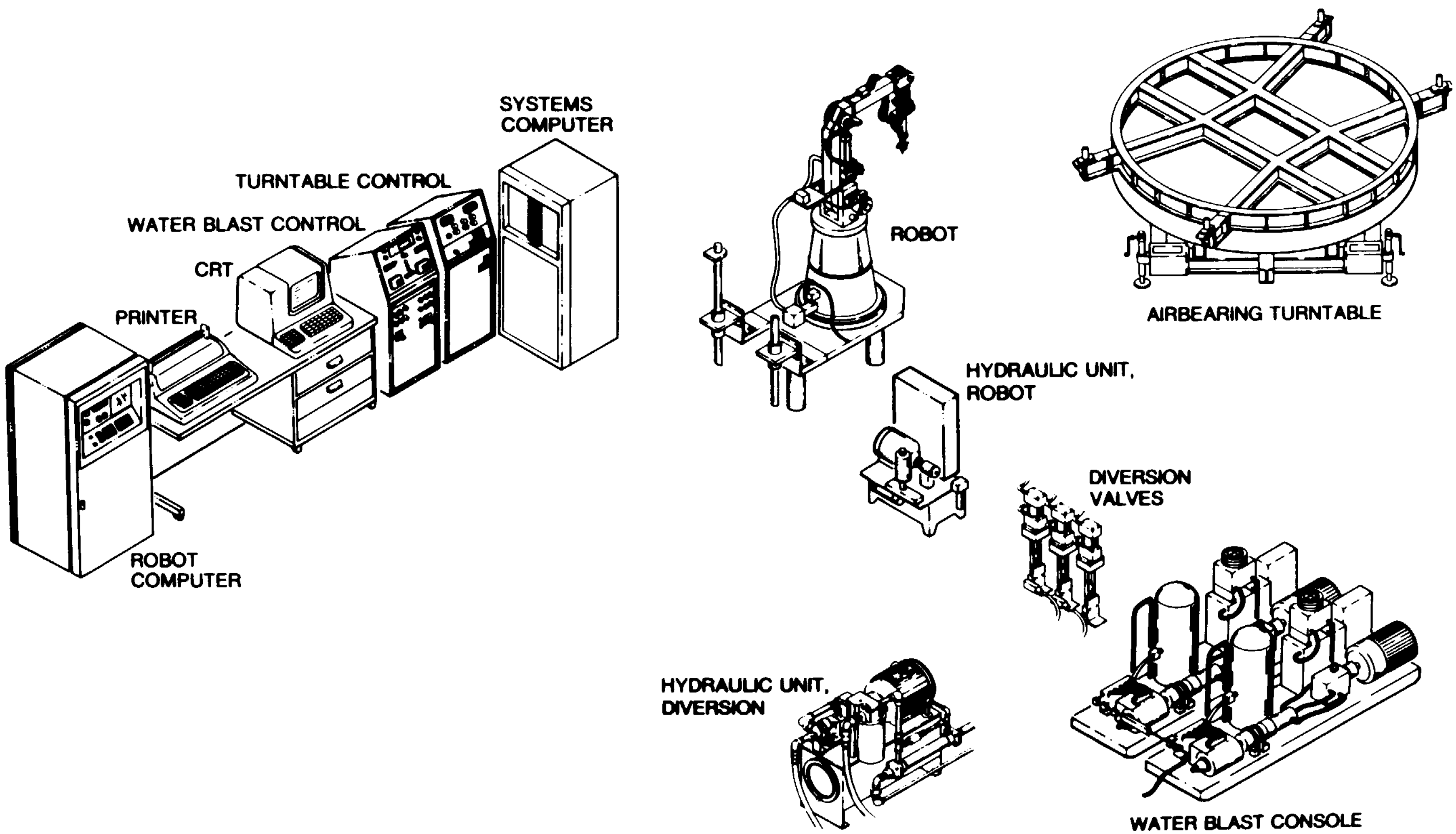

FIGURE 2

MOBILE ROBOTIC HYDROLASING SYSTEM